UNIVERSITY OF PENNSYLVANIA

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A DISSERTATION

IN PHYSICS

PRESENTED TO THE FACULTY OF THE GRADUATE SCHOOL IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

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Reprint from

THE PHYSICAL REVIEW, 60 (1941)

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Reprinted from THE PHYSICAL REVIEW, Vol. 60, No. 6, 430–434, September 15, 1941
Printed in U. S. A.

Radiations from Radioactive Cobalt

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(Received June 19, 1941)

A cloud chamber has been built and is briefly described. It has been used for measuring the energies of the radiations from the long-lived cobalt isotopes, $Co^{56,58}$, formed by deuteron bombardment of iron. A positron spectrum with a maximum energy of 1.36 ± 0.10 Mev was observed on the histogram. The K-U plot of the data suggests also another spectrum with an energy end point near 0.5 Mev. One internally converted γ-ray near 0.1 Mev was observed in the cloud chamber and resolved into two lines at 117 kev and 130 kev, respectively, by a magnetic spectrograph. Still higher energy γ-rays less intensely internally converted are suggested.

The histogram from a sample of Co^{58} produced by bombarding manganese with α-particles definitely assigns the higher energy positron spectrum to the isotope Co^{58}.

INTRODUCTION

THE activities of the radioactive isotopes of cobalt have been fairly definitely assigned, though the details of the latest investigations have not yet been published. Sampson, Ridenour, and Bleakney[1] were the first to observe long period activity in cobalt when a sample of cobalt was bombarded with slow neutrons. Risser[2] later observed the same activity, and estimated the half-life at 2 years. This value has lately been changed to 5.5 years by Livingood and Seaborg[3] who have followed the activities of chemically separated cobalt samples for some years. Livingood and Seaborg[4] also observed this period in deuteron-activated cobalt. These reactions result in both Co^{58} and Co^{60}, but a half-life of 72 days[3] has been assigned to the isotope Co^{58} by Livingood and Seaborg, who produced this single isotope by bombarding manganese with 16-Mev α-particles;[4] therefore, the long period presumably is to be associated with the isotope Co^{60}. The same shorter period was also observed in their[4] samples of cobalt bombarded with neutrons and deuterons, and later observed by Viktorin[5] in nickel activated by fast neutrons; Livingood and Seaborg[3] confirm the Ni(n, p) reaction.

Perrier *et al.*[6] first observed an activity whose period has been corrected to 270 days[3] in a sample which had a strong iron impurity[4] bombarded with deuterons. In this same sample they also found an indication of what must have been the 72-day Co^{58}. The 270-day activity was produced by Livingood and Seaborg[4] with protons on iron. These two reactions can produce the cobalt isotopes having mass numbers 55, 56, and 58, but since the 72-day activity has already been assigned to Co^{58} by the Mn$+\alpha$ reaction and the 18.2-hour activity of Co^{55} produced by lower energy deuterons has been well known for a long time,[7] the 270-day activity probably belongs to Co^{56}, as it has been assigned.[3] The isotope chart in Fig. 1 summarizes these assignments.

It was pointed out by Perrier *et al.*[6] that most of the particles from their Fe$+d$ sample consisted of electrons, but except for this and the absorption measurements, unpublished except for their results, of Livingood and Seaborg,[3] no attempt has been made to measure the energies of the radiation from the cobalt isotopes 56 and 58. This series of experiments is an attempt to gather more precise information on the radiation energies. A preliminary report of these investigations has already been published.[8]

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[1] M. B. Sampson, L. N. Ridenour, and W. Bleakney, Phys. Rev. **50**, 382L (1936).

[2] J. R. Risser, Phys. Rev. **52**, 768 (1937).

[3] G. T. Seaborg, Chem. Rev. **27**, 199 (1940).

[4] J. J. Livingood and G. T. Seaborg, Phys. Rev. **53**, 847L (1938).

[5] O. Viktorin, Proc. Camb. Phil. Soc. **34**, 612 (1938).

[6] C. Perrier, M. Santangelo and E. Segrè, Phys. Rev. **53**, 104L (1938).

[7] B. T. Darling, B. R. Curtis and J. M. Cork, Phys. Rev. **51**, 1010A (1937).

[8] A. S. Jensen, Phys. Rev. **59**, 936A (1941).

A sample of iron bombarded in the 60-inch cyclotron at Berkeley with 16-Mev deuterons was received from Professor Alvarez of the University of California. This bombardment may possibly result in the following observed reactions:

$$\mathrm{Fe}(d, n)\mathrm{Co}^{55, 58},$$
$$\mathrm{Fe}(d, 2n)\mathrm{Co}^{56, 58},$$
$$\mathrm{Fe}(d, p)\mathrm{Fe}^{55, 59},$$
$$\mathrm{Fe}(d, \alpha)\mathrm{Mn}^{52, 54, 56}.$$

The stable isotopes $\mathrm{Co}^{57, 59}$, $\mathrm{Fe}^{57, 58}$ and Mn^{55} in either the ground or excited nuclear states are also possible results.

The sample was aged for five months between the time of bombardment and the time of these investigations, thus allowing all but the longer lived activities to decrease to a negligible amount so that, effectively, only $\mathrm{Co}^{56, 58}$, $\mathrm{Fe}^{55, 59}$, and Mn^{54} existed during the experiments. Part of this particular sample had been removed chemically before it was received, so that it consisted mainly of cobalt.

Since the sample contained long periods of iron and manganese as well as the cobalt, a chemical separation was necessary. The iron was removed by the isopropyl ether process (in a ferric solution $8N$ in HCl). In the absence of chlorides, and from a solution of the remainder $1N$ in HNO_3, $KBrO_3$ removed manganese as MnO_2. Cobalt was precipitated as a sulphide from the latter filtrate. The final filtrate contained negligible activity. This sample contained, then, only the 72-day (Co^{58}) and the 270-day (Co^{56}) activities.[3]

A second sample consisting of MnO_2 which was bombarded in the same cyclotron with one microampere-hour of 16-Mev α-particles was also sent to us by Dr. Alvarez. From the isotope chart in Fig. 1, it can be seen that this reaction can produce only stable isotopes and Co^{58}; no chemical separation was thought to be necessary for this sample.

Apparatus

The apparatus which was used for this investigation was an automatic Wilson cloud chamber in a magnetic field, built in this laboratory by Dr. I. C. Cornog and the author. The basic design is quite similar to that of the chambers used by Crane[9] and Delsasso. The sensitive portion of the chamber is 6.5 inches in diameter and 1 inch deep. The piston is cocked by compressed air and the chamber expanded by breaking the circuit of a locking magnet. The clearing field potential of 150 volts is applied between an Aquadag ring on the glass chamber top and the chassis, and grounded out at the instant of expansion. The cycle of events is initiated by a telechron clock, while successive operations are controlled by micro-switches on a camshaft driven by a motor. An electron tube time delay circuit controls the time between the cocking and the expanding of the chamber. The electric control circuit is so designed that the cycle of events, once started, cannot be interrupted except by power failure. Also the switches that put the chamber into operation may be thrown in any order so that the

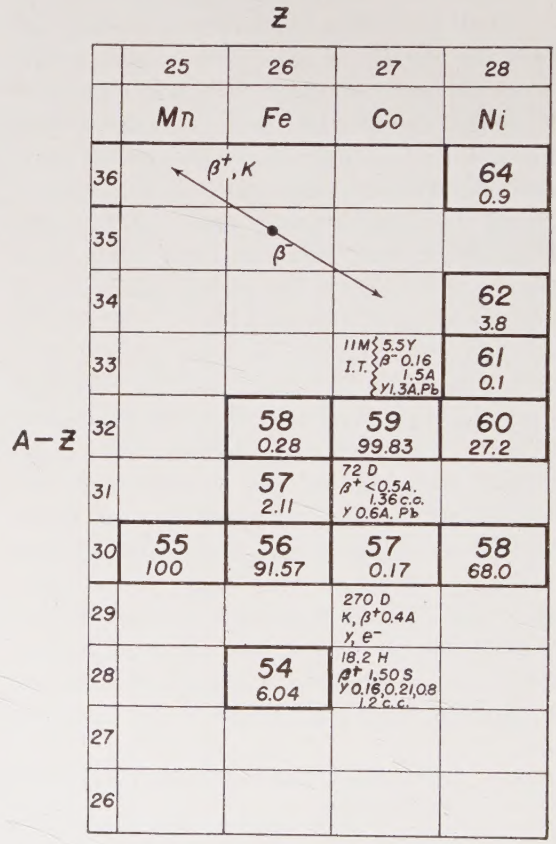

Fig. 1. Isotope chart in the region near cobalt. The data for this chart was taken from G. T. Seaborg, Chem. Rev. 27, 199 (1940). The positron spectrum assigned by this paper is included. A—Absorption; C.C.—cloud chamber; S—spectrograph.

[9] H. R. Crane, Rev. Sci. Inst. 8, 440 (1937).

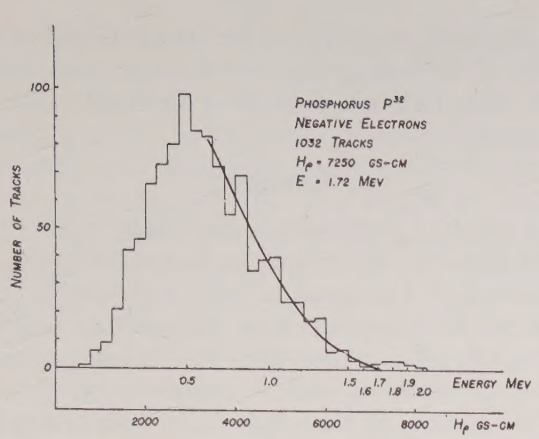

FIG. 2. Histogram of negative electrons from P^{32} showing a single β^--spectrum. Magnetic field strength 540 and 380 gauss.

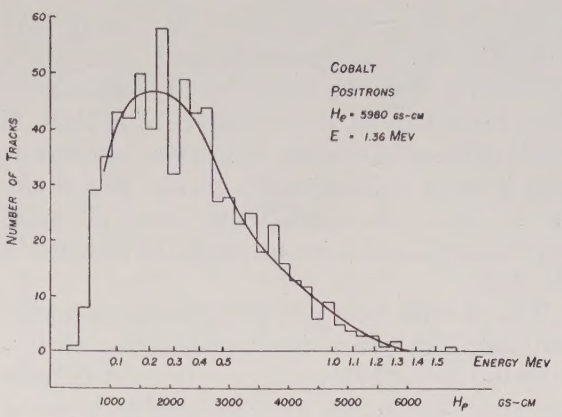

FIG. 3. Histogram of positrons from $Co^{56,58}$. Magnetic field strength 396 gauss.

machine is practically foolproof and can be used as a general laboratory instrument.

The field coils, which were wound with No. 7 square copper wire, are placed approximately in the Helmholtz position. The field was measured by turning it on and off while a search coil was in position. It has a measured constant of 23.3 gauss per ampere which is constant to within 1 percent throughout the sensitive portion of the chamber. The field is turned on about one second before the expansion and off again about three seconds later by means of a "Durakool" mercury switch that makes and breaks a 60-ampere current three times per minute without heating. The ammeter used to measure the current through the coils during the measurement of the field is also used during their operation, and has been checked against a calibrated Weston ammeter.

To reduce scattering, the tracks were photographed in helium, at a pressure slightly above atmospheric. The helium was bubbled through a mixture of *n*-propyl alcohol and water, but to insure saturation of the atmosphere, before the chamber was closed from the air some alcohol was placed on the velvet piston covering that forms the photographic background.

With a Sept motion picture camera, having a 50 mm $f/3.5$ lens, an exposure of 1–10 second at $f/5$ on Eastman Kodak Super XX film was found to be sufficient. The chamber is illuminated through two opposing windows in the walls by four 200-watt G.E. "Covelite" bulbs which are burned at 50 volts normally and at 220 volts during the exposure. There are two bulbs on each side of the chamber. These "Covelite" bulbs are the regular, horizontal U-filament bulbs aluminized on one side to reflect the light. We have found, as have others, that burning the lamps at a lower voltage between flashes substantially lengthens their lives. After approximately 3000 flashes one of the first set of four blew out; the others lasted for about 4000 flashes. The light is brought into a fairly parallel beam by cylindrical condenser lenses, and is further collimated by horizontal slits painted with Aquadag on the chamber wall. Shutters that operate just before and just after the exposure keep the chamber dark at all other times to prevent the heat from the lights from disturbing the temperature equilibrium of the chamber.

EXPERIMENTAL METHOD

The criteria that have been used as guides for the choice of measurable tracks are similar to those which have come to be recognized by other investigators:[10] (1) A track must appear to originate at the source. (2) It must be clear and sharply defined enough to allow measurement to ± 0.5 cm. (3) It must have a constant radius of curvature from the source to the end of the portion considered. (4) Track length: (a) If the radius of curvature is less than 5 cm, the track must make an arc of at least one radian. (b) If $5 < \rho < 15$ cm, the track must be at least 5 cm in

[10] J. R. Richardson and F. N. D. Kurie, Phys. Rev. **50**, 999 (1936).

length. (c) If $\rho > 15$ cm, the track must be long enough (>5 cm) to be unambiguously measurable to ± 0.5 cm when the measurement is repeated at least five times. It is impossible for a track of small radius of curvature to meet a requirement that it be of a given length greater than 5 cm, yet in many cases this track meets all other requirements, and, it seems, should be included in the data.

The pictures were projected through a standard projection system onto a ground glass set in a table top above the projector, and viewed through the glass. The tracks were matched by a set of curves engraved ($\Delta\rho = 0.5$ cm) on a clear celluloid sheet. This set was checked both before and after measuring the tracks to eliminate shrinkage errors. The magnification of the projected tracks was determined by measuring the image of a chromium-plated bar placed in the chamber and photographed simultaneously with the tracks.

TABLE I. P^{32} β^--*spectrum end-point energy (Mev).*

Investigator	$H\rho$ Curve	K–U Plot	Fermi Plot	Method
F. N. D. Kurie *et al.**	1.8	2.15	1.89	cl. ch.
E. M. Lyman†	1.69	2.09	1.69	spect.
J. L. Lawson‡	1.72	2.2	1.72	spect.
A. S. Jensen (this paper)	1.72	2.09	1.77	cl. ch.

* F. N. D. Kurie *et al.*, Phys. Rev. **49**, 368 (1936).
† E. M. Lyman, Phys. Rev. **51**, 1 (1937).
‡ J. L. Lawson, Phys. Rev. **56**, 131 (1939).

The total error in measurement of energies about 1 Mev is estimated for our technique to be less than 10 percent, and, of course, is greater for lower energies. From an investigation of the β^--spectrum of P^{32}, however, the actual error is somewhat smaller since the author agreed with other investigators to within 5 percent (see Fig. 2 and Table I).

The sample produced by the Fe+d reaction was plated from a chloride bath onto a copper strip about 4 mm $\times$22 mm to a density of about 1 mg per cm^2. This strip was cemented with rubber cement to a strip of brass bent in the form of an inverted "L" and waxed with Apiezon "Q" to the glass chamber top.

The second sample, produced by bombarding MnO_2 with α-particles, had a very small specific activity so that only a thick source could be made. All of the activated MnO_2 was bound on a piece of Cellophane tape with water glass, and this tape fastened to another inverted "L" of copper.

Results

A total of 1410 measurable tracks from the Fe+d source were photographed showing both positrons and electrons as well as a γ-ray background. Of these, 693 were of positrons which when plotted as a histogram (Fig. 3) indicate one positron spectrum with a maximum energy at 5980 gauss-cm or 1.36 ± 0.10 Mev. This is in fair agreement with an unpublished measurement made by Livingood and Seaborg which gave 0.45 g/cm^2 range in aluminum for radiation from cobalt made by a Ni(d, α)Co reaction. This range in aluminum indicates by the relationship given by Widdowson and Champion:[11] Energy (Mev) = (range in g/cm^2 + 0.165)/0.536, an energy of 1.2 Mev. A K–U plot of these positrons (Fig. 4), however, shows a change in curvature that indicates a preponderance of low energy particles.

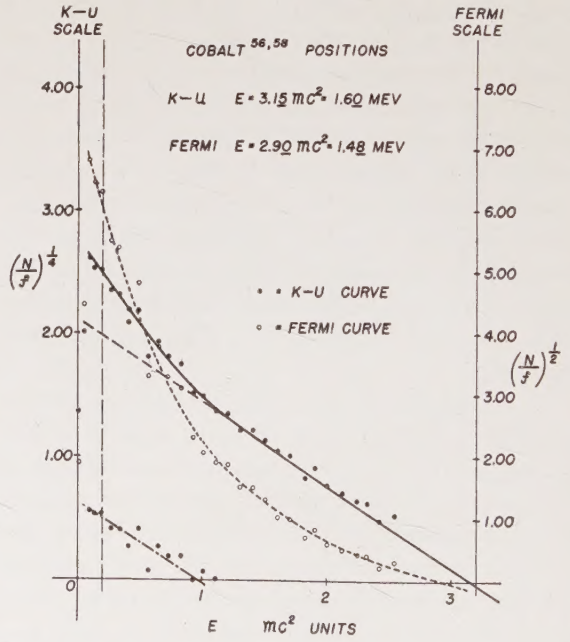

FIG. 4. K-U and Fermi plots of data from $CO^{56,58}$ positrons. Dashed axis indicates estimated lower energy limit of accurate data. Solid line is the K-U curve; dotted, Fermi. Dash-dotted line represents the difference curve obtained graphically from the dashed extrapolated straight line.

[11] Widdowson and Champion, Proc. Phys. Soc. **50**, 192 (1938).

The difference curve suggests a second positron spectrum with an energy end point near 0.5 Mev. This would be in good agreement with the measurement given by Livingood and Seaborg in their table of radioactive isotopes[3] (see Fig. 1).

From the second (Mn+α) sample a total of 143 measurable positron tracks was observed, and a histogram plot (Fig. 5) of these definitely shows an upper energy limit near 1.3 Mev when allowance is made for a thick source and the small number of tracks. This assigns the 1.36-Mev positron spectrum to the 72-day isotope, Co^{58}. On the same series of pictures, 53 measurable tracks of negative electrons were observed. These are too few to show any definite grouping in a histogram, but showed some grouping around 0.1 Mev, while some had energies up to 0.6 Mev. These are very likely Compton recoil electrons produced in the thick source by γ-rays from the Co^{58}.

The other 717 tracks from the Fe+d sample were of negative electrons, whose momentum distribution (Fig. 6) suggests an internally converted γ-ray near 0.1 Mev. This was confirmed by a magnetic spectrograph investigation of the radiation of negative charge made by this author together with E. Plesset of this laboratory,[12] which showed two internally converted γ-rays at 117±2 kev and 130±2 kev respectively. The higher energy tracks in the cloud-chamber distribution curve suggest the existence of higher energy γ-rays that are less frequently internally converted, perhaps the 0.6-Mev γ-ray already reported[3] or one of the difference energy of the two positron spectra. An investigation of these is being made.

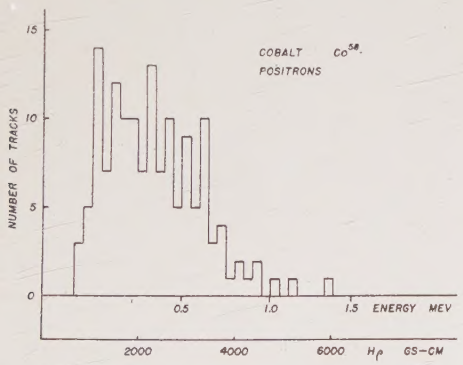

FIG. 5. Positron spectrum from Co^{58}. Magnetic field strength 396 gauss.

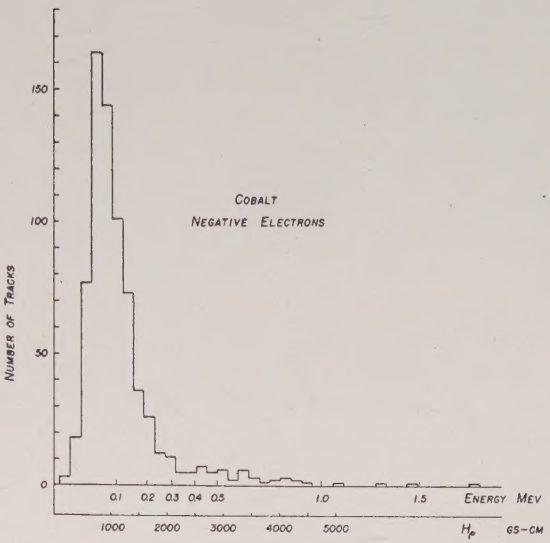

FIG. 6. Negative electrons from $Co^{56,58}$.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Professor Luis W. Alvarez of the University of California for the samples used in this research, to Professor W. McNabb of the Chemistry Department of the University of Pennsylvania for his patient advice on the separation of the sample, and to Professor Louis N. Ridenour for his competent advice and guidance. It has been a pleasure for the author to work in this laboratory with Dr. I. Clyde Cornog whose efforts and planning alone are responsible for the successful operation of the cloud chamber, and whose advice on problems of experimental technique was so useful. All of this research was done while the author was enjoying the privileges of the Hector Tyndale and the George Leib Harrison Fellowships at this university.

[12] E. H. Plesset, Phys. Rev. 59, 936A (1941).

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